SEY AND ELECTRON CLOUD BUILD-UP WITH NEG MATERIALS

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Abstract

The LHC room temperature sections will be coated with non-evaporable getter (NEG) materials for, among other reasons, their properties of antimultipactor.

Laboratory measurements of secondary electron yields (SEY) of TiZrV NEG coatings have shown that after 2 h heat treatment at 160 and 200 C, the maximum SEY decreases from 2 to below 1.4 and 1.1 respectively. Saturation with H_2, H_2O, CO and CO_2 at low pressure increases the SEY by about 0.1. This outcome is supported by the results on a NEG-coated chamber in the SPS accelerator ring, with LHC type proton beam. The untreated NEG surface multipacts as any unbaked surface, while no electron cloud build-up was observed after 4 h heat treatment at 250 C and subsequent saturation, mainly with water vapour.

We give here a summary of secondary electron yield (SEY) measurements on NEG surfaces and present the results of electron cloud build-up measurements with NEG-coated vacuum chambers.

INTRODUCTION

TiZrV NEG coating [1, 2] will be employed in the LHC experimental regions and in the room temperature parts of the long straight sections (LSS). After baking, NEG coating works against ion induced pressure instability being a low mass pump, and to reduce the background pressure since it is characterised by low stimulated gas desorption yields. Another useful feature is the NEG low secondary electron emission that should allow limiting electron cloud build-up. This effect is detrimental for beam operations both for the direct interactions of the electron cloud with the beam, and because electron stimulated desorption is a source of residual gas.

Laboratory measurements of SEY were performed on TiZr and TiZrV thin films (~1 μm) deposited onto chemically polished copper substrates [3]. The samples were bombarded with low intensity (~ 5×10^{-9} A) pulses of primary electrons at normal incidence, and energies between 60 eV to 3 keV, giving a total dose < 10^{-8} C/mm^2 [4]. Figure 1 shows the SEY of TiZrV samples after the different temperature treatments. An important decrease of the maximum SEY (δ_{max}) from > 2 to <1.4 was observed already after 2 h at 200 C (TiZr) and 160 C (TiZrV) [3], i.e. below the activation temperature [1, 2]. A value δ_{max}~1.1 was measured after 2 h at 250 C (TiZr) and 200 C (TiZrV) [3]. The effect of surface contamination was evaluated after exposure to a flux of about 4 Pa·s of H_2, H_2O, CO and CO_2* to be about $\Delta\delta_{max}$ < 0.1 [3, 5]. Moreover, a small deterioration of the SEY (δ_{max}~1.4) was noticed due to NEG aging, i.e. after opening to air several times and reconditioning (250 C x 24 h) [6]. The latter measurement was performed in unfavourable conditions since the sample size was much smaller than the uncoated stainless steel surface of the measuring chamber.

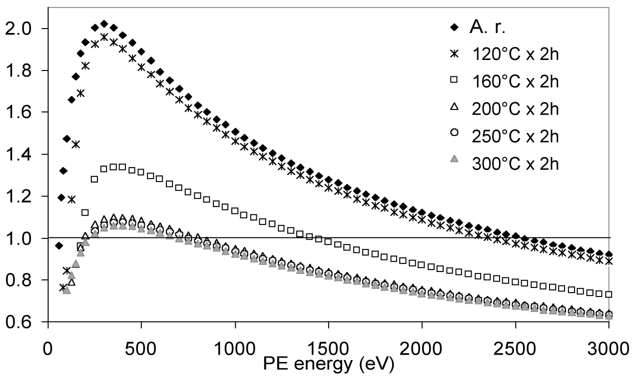

Figure 1: SEY of TiZrV samples for several activation temperatures (A.r. means "as received"). Courtesy of C. Scheuerlein [3].

EXPERIMENTAL SET UP

To verify the effectiveness of NEG coating as antimultipactor, an experiment was set in the CERN SPS facility, as pictured in Figure 2. It is composed by two type of chambers: a 6-m long reference chamber, made of stainless steel, and a NEG-coated stainless steel chamber of the same length.

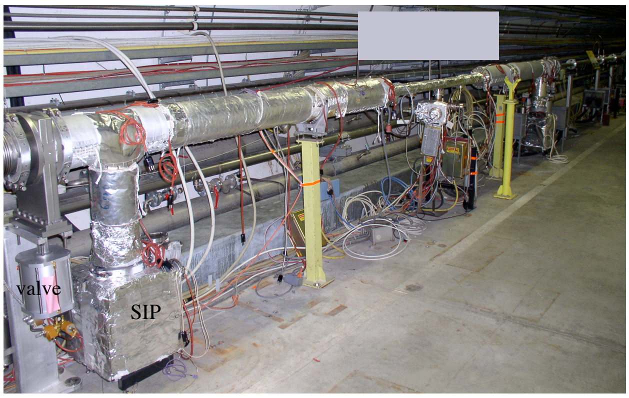

Figure 2: Experimental set up in the SPS (NEG-coated chambers).

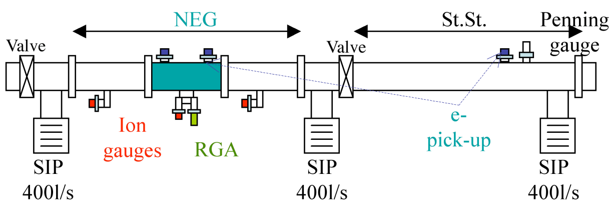

Figure 3: Schematic layout of the beam vacuum chamber.

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* Hydrogen and CO exposure on copper-coated samples and water and CO_2 on 316LN stainless steel coated samples.

As shown schematically in Figure 3, sputter ion pumps (SIP) are located at the two ends of the NEG-coated chamber to reduce contamination from the unbaked parts of the machine. The uncoated chamber has the same pump configuration for symmetry. The NEG-coated chambers are composed of 2-m long sections, each equipped with a pressure gauge type Bayard-Alpert (BA) ionisation gauge at their centre. In the first set of measurements, the internal diameter of all the sections was 156 mm, where it was thought [7] that the electron cloud activity is more sensitive to small variations of δ_{max}. Subsequently, the central chamber was replaced with another one with a rectangular profile (H=129 mm, V=51.5 mm). The horizontal dimension could not be reduced further because of the beam stay-clear requirements for certain types of SPS operations (called “fixed target”). The vertical dimension was chosen in the region where the maximum electron cloud activity was expected (at least with a cylindrical chamber [7]). In addition to the pressure gauge, the central chamber is provided with a residual gas analyser (RGA) type Balzers QMG112, and two shielded electron pick-up devices. The uncoated reference chamber is equipped with an electron pick-up and a cold cathode pressure gauge. Its geometry was the same as the NEG central chamber.

Electron pick-ups

The electron pick-ups are floating metal buttons, which collect the electrons accelerated towards them. The pick-ups are screened with a grid that ensures electrical continuity along the beam pipe and therefore minimises the pipe impedance and image currents in the pick-ups. The electric signal is transmitted to an oscilloscope via screened cable. The data shown in the following are collected in the “condenser” mode, i.e. represent the voltage induced by instantaneous charge collected on the pick-up. The output impedance of the oscilloscope was set to 1 MΩ.

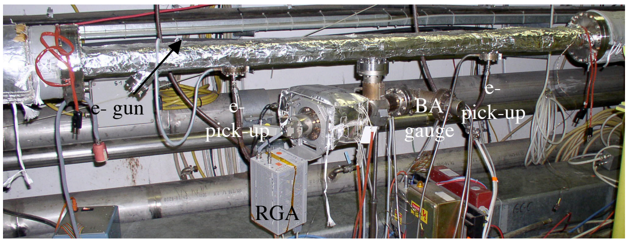

Figure 4: Particular of the central NEG-coated chamber after the installation of the electron gun

Electron gun

In the LHC the primary electrons will be mainly photoelectrons, ~10^{14} e^-/m in the LSS at nominal beam current, i.e. orders of magnitude larger than the electron yield from residual gas ionisation in the SPS. We wanted to verify that seeding (or primary) electrons do not influence the electron cloud formation. To this purpose, in 2003, an electron gun was installed in a new NEG-coated chamber. The gun is a simple device with a hot filament generating electrons, which are then accelerated by an electric grid. The gun was calibrated to obtain ~ 1 mA electrons at 200 eV. These electrons enter the NEG-coated chamber at 45° angle on the flat part of the chamber, at a distance between 15 and 20 cm from the first electron pick-up (on the left-hand side in Figure 4). The impact location and incident angle simulate a localised source of electrons due, for example, to concentrated photon losses upstream of the measuring device. With photoelectron yields of the order of 10^{-2}, this source would correspond to about 10^{17} to 10^{18} incident photons over about 1 to 2 cm.

MEASUREMENTS PARAMETERS

Beam parameters

Measurements were taken with what is called “LHC type beam”, whose characteristics are listed in Table 1. Unless specified, the beam energy was the same as at injection, namely 26 GeV.

Table 1: LHC-type beam in the SPS ring

No. of batches	1 to 4	
No. of bunches per batch	72	
Distance between batches	25	ns
Bunch length at injection	4	ns
Beam energy	26 to 450	GeV

NEG surface parameters

As explained in the introduction, NEG surface characteristics, and in particular the SEY, vary with surface conditioning and history. The expected SEY are reported in Table 2 for the different cases.

Table 2: Expected maximum SEY

Non-activated NEG	> 2
NEG activated and saturated	~ 1.2
NEG cycled (exposed to air at atmospheric pressure and re-conditioned) 7 times	≤ 1.4

RESULTS

Non-activated NEG

When the NEG is exposed to atmospheric air and not reactivated, its δ_{max} is generally larger than 2. In this case, electron cloud is expected to build up, as it was verified with rectangular geometry cross section. Figure 5 shows electron cloud activity both in the non-activated NEG-coated chamber and in the unbaked stainless steel reference chamber. In the NEG-coated chamber the electron cloud needs 2 batches to develop, while only one circulating batch is sufficient to trigger it in the reference chamber. Moreover, the level of activity appears to be about 10 times lower with NEG coating, as indicated by the ratio of the vertical scales in the figure, maybe due to different SEY between the two chambers. When the beam is accelerated to 450 GeV, the signals are lower. This is probably due to the fact that the bunch length shortens with increasing energy and, secondarily, to beam losses.

NEG activated and saturated

The 156-mm ID NEG-coated chamber was activated for the first time by baking the uncoated parts and

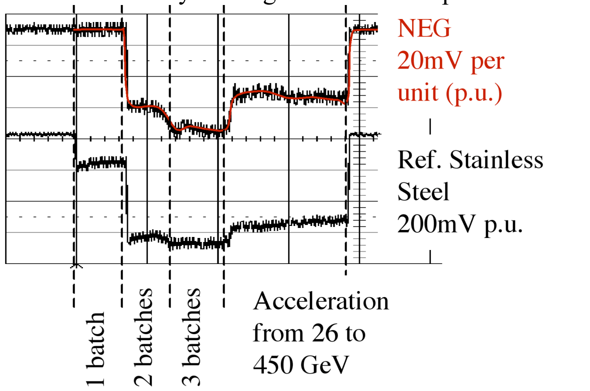

Figure 5: Pick-up signals measured with 1 to 3 batches LHC-type beam, in a rectangular profile non-activated NEG-coated chambers (upper red line) and in an unbaked stainless steel chamber (lower black line). The vertical scale for the NEG-coated chamber is 20 mV per unit (p.u.) and 200 mV p.u. for the other curve. The horizontal scale is 5 s p.u.

subsequently activating the NEG at 200 C for 24 h. During this operation, the valves at the ends of the NEG-coated chambers were kept closed. The pressure after activation (with ion pumps on) was of the order of 10^{-11} Torr. After the valves are opened to the unbaked machine, the NEG slowly saturates.

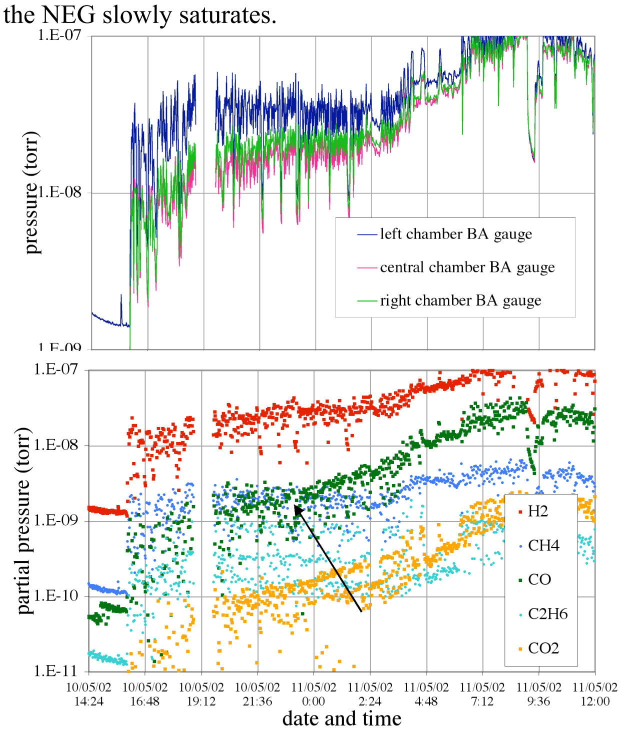

Figure 6: Total (upper picture) and partial pressure (lower picture) as a function of time in the NEG-coated chamber. Evidence of NEG saturation can be inferred by the fact that the CO signal becomes larger than methane and from the pressure distribution along the chamber.

Evidence of NEG saturations was observed after about one day from the opening of the NEG system to the SPS atmosphere, as pictured in Figure 6, which shows the recorded pressure as a function of time. The first part of the curves shows the pressure without beam. The rest was recorded during 1-batch operations.

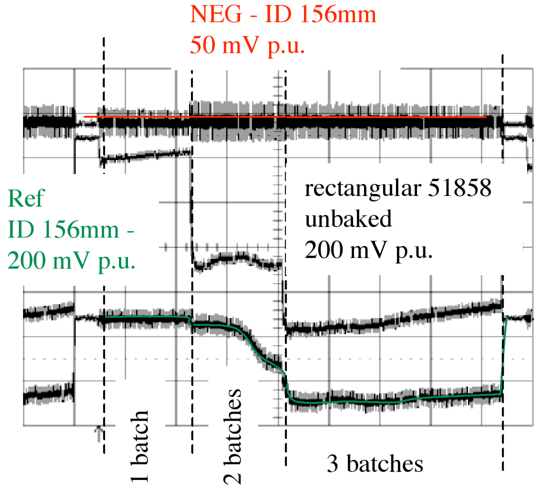

Figure 7: Pick-up signals measured with 1 to 3 batches LHC-type beam, in activated and saturated NEG-coated chamber of ID 156 mm (uppermost curve, highlighted with a red line), in a stainless steel unbaked chamber, of the same diameter (lowest curve highlighted with a green line) and in a stainless steel unbaked chamber with rectangular profile (mid curve). The horizontal scale is 2 s p.u.

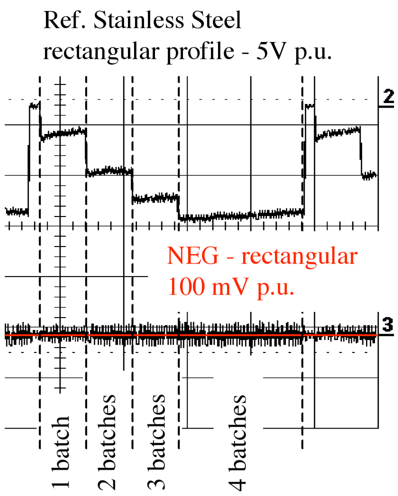

Figure 8: Pick-up signals measured with rectangular geometry and 1 to 4 batches LHC-type beam, in an activated and saturated NEG-coated chamber (lowest curve highlighted with a red line) and a stainless steel unbaked chamber (uppermost curve). The horizontal scale is 5 s p.u.

One can see that without beam and at the very beginning of beam operation, the gas composition is dominated by hydrogen (red dots) and methane (blue dots), as expected, since CO, which typically is the second most abundant species after hydrogen in a vacuum system, is very well pumped by the NEG. At a later time (as pointed out by the arrow in the figure), the composition changes and CO (green dots) becomes larger than methane, indicating NEG saturation. The pressure distribution, as seen in the uppermost part of Figure 6, supports this conclusion. The pressure is in fact lowest in the middle of the NEG-coated chamber (pink line) were the effect of the ends is the lowest. As time passes, the distribution tends to flatten, and later in time it will even reverse, since the NEG will not pump any longer, while the two ion pumps at the ends impose a lower pressure.

The NEG δ_{max} expected in this case is about 1.2. The data collected for this case are shown in Figure 7. The NEG surface does not exhibit any electron cloud signal. The same measurements were repeated with the rectangular cross section chambers. In this case the chamber was activated at 250 C for 4 h. Also in this case the NEG saturated after a couple of days. No electron cloud activity could be observed in the NEG-coated chamber, as pictured in Figure 8.

Cycled NEG

The rectangular cross section NEG-coated chamber was exposed to atmospheric air for at least 30 min and reactivated for 7 more times to try and increase its SEY and simulate NEG aging. The activation cycles were performed at 250 C for 4 h, with the valves closed, and a pumping speed for H_2 decreasing after each cycle was measured, as expected. After the last activation the valves were opened and the NEG progressively saturated.

Despite the higher expected SEY, no electron activity could be detected, as shown in Figure 9. It should be noted, nevertheless, that δ_{max} obtained with NEG aging is below 1.5, which is the minimum value achieved on copper, after scrubbing, in the SPS [8]. Therefore, the NEG SEY is probably below the threshold for the SPS.

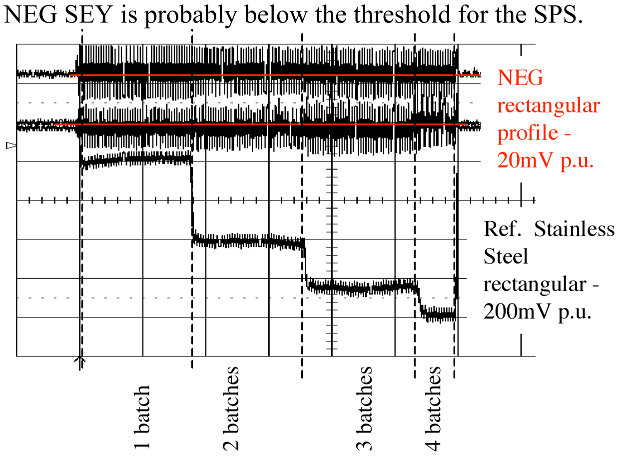

Figure 9: Pick-up signals measured with rectangular geometry and 1 to 4 batches LHC type beam, in a NEG-coated chamber (first two curves highlighted with a red line) after several opening to atmospheric air and reconditioning and a stainless steel unbaked chamber (lowest curve). The horizontal scale is 2 s p.u.

Electron cloud measurements with seeding electrons

The central chamber of the NEG-coated section was replaced with a new chamber of same rectangular cross section, able to house an electron gun. The NEG surface was activated and exposed to atmospheric air twice prior to the data acquisition. As mentioned before, during the measurements, the electron gun provided about 1 mA of electrons at 200 eV, hitting the flat part of the chamber at 45° angle, at a distance between 15 and 20 cm from the electron pick-up whose signal is labelled “1” in Figure 10 and Figure 11. Figure 10 refers to operations with 75 ns batch spacing. No electron cloud activity is detected in either the NEG-coated or the reference chamber.

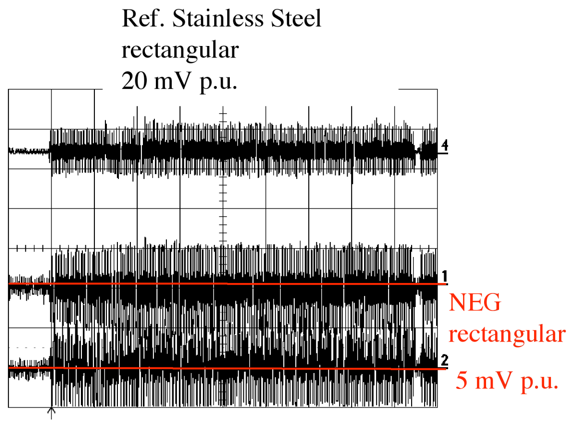

Figure 10: Pick-up signals measured with 1 to 4 batches LHC-type beam with 75 ns batch spacing. The NEG-coated chamber has a rectangular profile, and has been opened to atmospheric air and reconditioned twice. A current of 1 mA of primary electrons at 200 eV are injected upstream of the pick-up on the l.h.s. of the NEG-coated chamber (line 1). The horizontal scale is 5 s p.u.

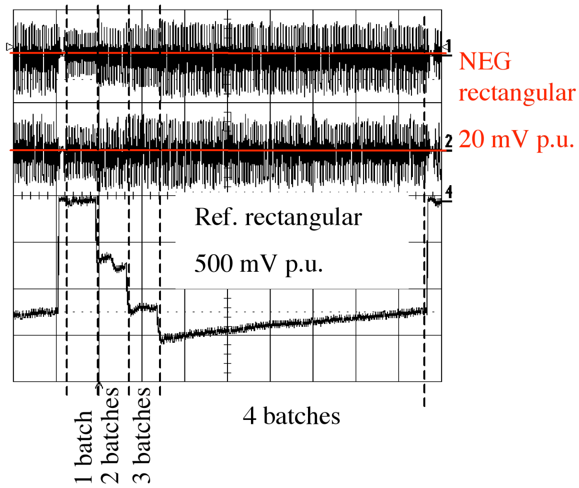

Figure 11: Pick-up signals measured with 1 to 4 batches LHC-type beam with 25 ns batch spacing. A current of 1 mA of primary electrons at 200 eV are injected upstream of the pick-up on the l.h.s. of the NEG-coated chamber (line 1). The horizontal scale is 5 s p.u.

When the spacing between batches is reduced to 25 ns, the reference chamber multipacts, as it can be seen in Figure 11. In the NEG-coated chamber, instead, negligible electron cloud activity is detected despite the source of primary electrons. These electrons are not sufficient to start the electron cloud build up, at least as long as δ_{max} < 1.5, i.e. below the threshold value for electron cloud build-up in the SPS.

CONCLUSIONS

The employment of NEG coating as antimultipactor has been validated in the SPS, with LHC-type beam. The surface characteristics, and in particular the SEY was varied from above 2 to 1.1-1.2 by NEG activation. When the NEG is not activated, i.e. if its δ_{max} > 2 [3], an electron cloud builds up, as for other type of surfaces. After activation, whether the NEG is subsequently saturated or cycled (exposed to atmospheric air and reactivated) several times, its δ_{max} is measured to be ≤ 1.4 [3-5] and no electron cloud activity could be observed. This confirms that if the δ_{max} is below the electron cloud threshold, identified between 1.4 and 1.5 in the SPS field-free regions [8], the surfaces do not lead to multipacting.

Additional primary electrons have also been injected to check the effect of electron seeding upstream the measurement location. These electrons do not seem to start any electron cloud build up, at least if δ_{max} is below the threshold value.

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